Innovative Technologies for Volcanic Hazard Mitigation in the Pacific Islands

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Abstract: Volcanic hazards pose significant risks to Pacific island nations, where remoteness, rugged terrain, and limited infrastructure hinder effective monitoring. This paper presents a multi- technology strategy adapted to these challenges, combining low-cost, innovative instruments with community-based monitoring approaches. Integrated through cloud-based platforms, these tools enable real-time data access, improved eruption forecasting, and more effective early warning systems. Field applications demonstrate how the combination of ground-based and satellite-based methods enhances resilience and supports community-level risk reduction. This scalable and transdisciplinary framework offers a practical pathway for strengthening volcanic hazard monitoring and response across the Southwest Pacific.

1. INTRODUCTION

The Southwest Pacific spans roughly 8,000 kilometers of the Pacific Ring of Fire (PRF), representing about 20% of its total length, and hosts 117 of the estimated 1,500 Holocene volcanoes along the PRF [Global Volcanism Program, 2024]. Approximately one-third of these volcanoes are submarine. Papua New Guinea has the highest concentration with 41 volcanoes, followed by New Zealand (24), Tonga (21), Vanuatu (12), Solomon Islands (8), Fiji (2), and others in claimed territories. Including the hotspot volcanoes of French Polynesia, which lie outside the PRF, raises the total to 122 (Table 1). These volcanoes are organized into volcanic regions such as the Bismarck Sea, Solomon Arc, Vanuatu Arc, Kermadec Arc, Taupo Arc, and others across Oceania (Fig. 1). Collectively, these regions cover over 10 million km²—about 7% of Earth's total land surface, comparable in size to Europe. Excluding Australia, Oceania's GDP is relatively small and concentrated mainly in New Zealand, while other island nations face challenges of geographic isolation, limited infrastructure, and scarce resources. This paper examines how innovative technologies can address these challenges to support ongoing volcanic monitoring and hazard mitigation across the Pacific Islands.

Table 1. List of volcanoes in the broader Southwest Pacific, organized by volcanic region and corresponding country. Data from ref. [Global Volcanism Program, 2024]

Volcano	A or S*	Last eruption	Volcanic region	Country
Southwest Pacifi Volcanic Regions				
St. Andrew Strait	A	1957	Bismarck Sea	Papua New Guinea
Central Bismarck	S	1972	Bismarck Sea	Papua New Guinea
Lolo	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Witori	A	2012	Bismarck Volcanic arc	Papua New Guinea
Sulu Range	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Hargy	A	950	Bismarck Volcanic arc	Papua New Guinea

Bamus	A	1886	Bismarck Volcanic arc	Papua New Guinea
Ulawun	A	2025	Bismarck Volcanic arc	Papua New Guinea
Lolobau	A	1912	Bismarck Volcanic arc	Papua New Guinea
Rabaul	A	2014	Bismarck Volcanic arc	Papua New Guinea
Tavui	S	4946 BCE	Bismarck Volcanic arc	Papua New Guinea
Karkar	A	1979	Bismarck Volcanic arc	Papua New Guinea
Hankow Reef	S	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Long Island	A	1993	Bismarck Volcanic arc	Papua New Guinea
Umboi	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Ritter Island	A	2007	Bismarck Volcanic arc	Papua New Guinea
Sakar	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Langila	A	2025	Bismarck Volcanic arc	Papua New Guinea
Blup Blup	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Kadovar	A	2023	Bismarck Volcanic arc	Papua New Guinea
Bam	A	1960	Bismarck Volcanic arc	Papua New Guinea
Manam	A	2025	Bismarck Volcanic arc	Papua New Guinea
Dakataua	A	1895	Bismarck Volcanic arc	Papua New Guinea
Bola	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Garua Harbour	A	Unknown but believe to be holocene	Bismarck Volcanic arc	Papua New Guinea
Grummel-Garbuna-Welcker	A	2008	Bismarck Volcanic arc	Papua New Guinea
Lamington	A	1956	Trobriand Volcanic arc	Papua New Guinea

Hydrographers Range	A	Unknown but believe to be holocene	Trobriand Volcanic arc	Papua New Guinea
Managlase Plateau	A	Unknown but believe to be holocene	Trobriand Volcanic arc	Papua New Guinea
Victory	A	1935	Trobriand Volcanic arc	Papua New Guinea
Sessagara Hills	A	1944	Trobriand Volcanic arc	Papua New Guinea
Goodenough	A	Unknown but believe to be holocene	Trobriand Volcanic arc	Papua New Guinea
Iamalele	A	Unknown but believe to be holocene	Trobriand Volcanic arc	Papua New Guinea
Dawson Strait Group	A	1350	Trobriand Volcanic arc	Papua New Guinea
Lihi	A	Unknown but believe to be holocene	New Ireland Volcanic Arc	Papua New Guinea
Ambite	A	350	New Ireland Volcanic Arc	Papua New Guinea
Balbi	A	Unknown but believe to be holocene	Solomon Volcanic Arc	Papua New Guinea
Billy Mitchell	A	1580	Solomon Volcanic Arc	Papua New Guinea
Bagana	A	2025	Solomon Volcanic Arc	Papua New Guinea
Takuan Group	A	Unknown but believe to be holocene	Solomon Volcanic Arc	Papua New Guinea
Loloru	A	1050	Solomon Volcanic Arc	Papua New Guinea
Simbo	A	1910	Solomon Volcanic Arc	Solomon Islands
Kana Keoki	S	Unknown but believe to be holocene	Solomon Volcanic Arc	Solomon Islands
Coleman Seamount	S	Unknown but believe to be holocene	Solomon Volcanic Arc	Solomon Islands
Kavachi	S	2014	Solomon Volcanic Arc	Solomon Islands
Unnamed	S	Unknown but believe to be holocene	Solomon Volcanic Arc	Solomon Islands
Gallego	A	Unknown but believe to be holocene	Solomon Volcanic Arc	Solomon Islands
Savo	A	1847	Solomon Volcanic Arc	Solomon Islands
Tinakula	A	2024	Vanuatu Volcanic Arc	Solomon Islands
Ambae	A	2024	Vanuatu Volcanic Arc	Vanuatu
Ambrym	A	2024	Vanuatu Volcanic Arc	Vanuatu
Lopevi	A	2007	Vanuatu Volcanic Arc	Vanuatu
East Epi	S	2023	Vanuatu Volcanic Arc	Vanuatu
Kuwae	S	1974	Vanuatu Volcanic Arc	Vanuatu
Nguna-Emau	A	Unknown but believe to be holocene	Vanuatu Volcanic Arc	Vanuatu
Motlav	A	Unknown but believe to be holocene	Vanuatu Volcanic Arc	Vanuatu
Suretamatai	A	1966	Vanuatu Volcanic Arc	Vanuatu
Gaua	A	2022	Vanuatu Volcanic Arc	Vanuatu
Traitor’s Head	S	1881	Vanuatu Volcanic Arc	Vanuatu
Yasur	A	2025	Vanuatu Volcanic Arc	Vanuatu
Gemini-Oscostar	S	1996	Vanuatu Volcanic Arc	Vanuatu
Matthew Island	A	1956	Vanuatu Volcanic Arc	Claimed territory
Hunter Island	A	1903	Vanuatu Volcanic Arc	Claimed territory
Taveuni	A	1550	Fiji Volcanic Arc	Fiji
Nabekelevu	A	1660	Fiji Volcanic Arc	Fiji
Tonga-Kermadec Volcanic Regions				
Niuafo’ou	A	1946	Northeast Lau Basin volcanic group	Tonga
Dugong	S	Unknown but believe to be holocene	Northeast Lau Basin volcanic group	Tonga
Lobster	S	Unknown but believe to be holocene	Northeast Lau Basin volcanic group	Tonga
Tafu-Maka	S	2008	Northeast Lau Basin volcanic group	Tonga

West Mata	S	2009	Northeast Lau Basin volcanic group	Tonga
Niuatahi	S	Unknown but believe to be holocene	Northeast Lau Basin volcanic group	Tonga
Unnamed	S	1932	Tofua Volcanic Arc	Tonga
Unnamed	S	Unknown but believe to be holocene	Tofua Volcanic Arc	Tonga
Unnamed	S	2017	Tofua Volcanic Arc	Tonga
Hunga Tonga-Hunga Ha’apai	A	2022	Tofua Volcanic Arc	Tonga
Fonuafo’ou	S	1936	Tofua Volcanic Arc	Tonga
Tofua	A	2025	Tofua Volcanic Arc	Tonga
Kao	A	1847	Tofua Volcanic Arc	Tonga
Lateiki	A	2017	Tofua Volcanic Arc	Tonga
Home Reef	S	2025	Tofua Volcanic Arc	Tonga
Late	A	1854	Tofua Volcanic Arc	Tonga
Unnamed	S	2019	Tofua Volcanic Arc	Tonga
Fonualei	A	1957	Tofua Volcanic Arc	Tonga
Tafahi	A	Unknown but believe to be holocene	Tofua Volcanic Arc	Tonga
Curacoa	S	1979	Tofua Volcanic Arc	Tonga
Unnamed	S	Unknown but believe to be holocene	Northern Kermadec volcanic arc	Tonga
Raoul Island	A	2006	Northern Kermadec volcanic arc	New Zealand
Monowai	S	2014	Northern Kermadec volcanic arc	New Zealand
Wright	S	Unknown but believe to be holocene	Middle Kermadec volcanic arc	New Zealand
Havre Seamount	S	2014	Middle Kermadec volcanic arc	New Zealand
Curtis Island	A	Unknown but believe to be holocene	Middle Kermadec volcanic arc	New Zealand
Macauley	A	4360	Middle Kermadec volcanic arc	New Zealand
Giggenbach	S	Unknown but believe to be holocene	Middle Kermadec volcanic arc	New Zealand
Clark	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Tangaroa	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Rumble V	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Rumble IV	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Rumble III	S	2008	Southern Kermadec Volcanic arc	New Zealand
Rumble II West	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Healy	S	1360	Southern Kermadec Volcanic arc	New Zealand
Brother	S	Unknown but believe to be holocene	Southern Kermadec Volcanic arc	New Zealand
Mayor Island	A	5060 BCE	Taupo Volcanic arc	New Zealand
Whakaari/White Island	A	2025	Taupo Volcanic arc	New Zealand
Okatiana	A	1981	Taupo Volcanic arc	New Zealand
Taupo	A	260	Taupo Volcanic arc	New Zealand
Tongariro	A	2012	Taupo Volcanic arc	New Zealand
Ruapehu	A	2007	Taupo Volcanic arc	New Zealand
Auckland Volcanic Field	A	1446	Western North Island volcanic province	New Zealand
Kaikohe-Bay of islands	A	400	Western North Island volcanic province	New Zealand
Taranaki	A	1800	Western North Island volcanic province	New Zealand

Hotspot Volcanic Regions

Teahitia	S1985	Society islands Hotspot Volcano Group	French Polynesia
Rocard	S1972	Society islands Hotspot Volcano Group	French Polynesia
Moua Pihaa	S1970	Society islands Hotspot Volcano Group	French Polynesia
Mehetia	AUnknown but believe to be holocene	Society islands Hotspot Volcano Group	French Polynesia
Macdonald	S1989	Austral-Cook Hotspot Volcano Group	French Polynesia
Vailulu'u	S2003	Samoan Hotspot Volcano Group	American Samoa
Ta'u	AUnknown but believe to be holocene	Samoan Hotspot Volcano Group	American Samoa
Ofu-Olosega	A1866	Samoan Hotspot Volcano Group	American Samoa
Tutuila	A440	Samoan Hotspot Volcano Group	American Samoa
Malumalu	SUnknown but believe to be holocene	Samoan Hotspot Volcano Group	American Samoa
Upolu	AUnknown but believe to be holocene	Samoan Hotspot Volcano Group	Samoa
Savaii	A1911	Samoan Hotspot Volcano Group	Samoa

** A and S stand for Aerial and Submarin edifices respectively*

2. LOW-COST, INNOVATIVE NETWORKING OPTIONS FOR SMALL PACIFIC COUNTRIES

The goal is to develop a sustainable, affordable regional volcano monitoring system that enables data sharing, early warning, and research collaboration across Pacific island nations. Innovative low-cost instruments provide a practical means to monitor volcanic activity in remote or resource-limited areas by detecting seismic events, gas emissions, ground deformation, and thermal anomalies. Although less precise than high-end equipment, they reliably identify trends and deliver timely alerts. Their low power consumption and adaptability make them ideal for long-term, autonomous deployment. Importantly, these technologies empower community-based networks and strengthen local capacity for disaster preparedness. By expanding observational coverage and fostering regional cooperation, they have the potential to democratize volcanic monitoring and significantly enhance risk reduction across the southwest Pacific.

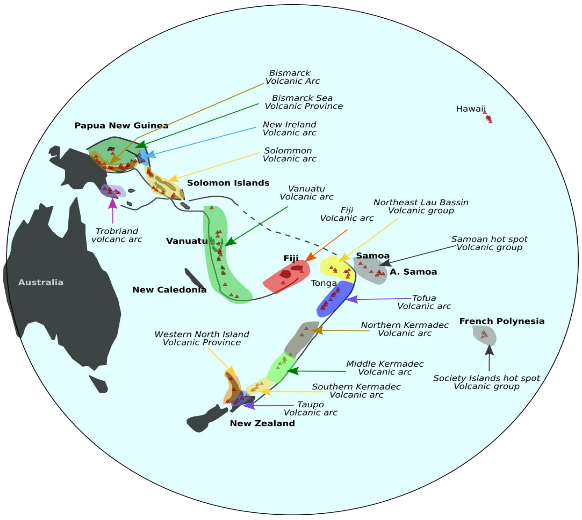

Fig. 1. *The broader Southwest Pacific volcanic regions.*

2.1 Seismic Sensors

A practical and cost-effective solution for monitoring seismic activity in Oceania is the Raspberry Shake (Fig.2), a compact seismograph built around the Raspberry Pi platform. With a unit cost ranging from approximately $500 to $800 USD, the Raspberry Shake is capable of recording both local and regional seismic events, including volcanic tremors and volcano-tectonic (VT) earthquakes. Its plug-and-play design makes it exceptionally easy to deploy, even in remote island environments with limited infrastructure. One of its most valuable features is its ability to stream data in real time to the global Raspberry Shake network (raspberryshake.org), enabling integration with international seismic databases and supporting both local monitoring and broader scientific collaboration.

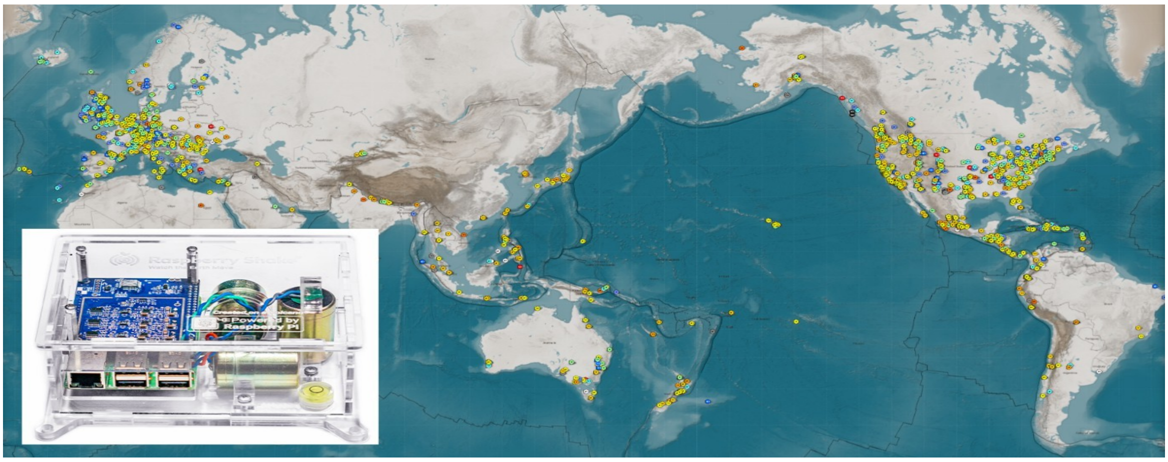

Fig. 2. *Global Raspberry Shake network, highlighting the limited number of stations in the Southwest Pacific region. The inset displays a typical 3D Raspberry Shake seismic station, showcasing its compact and field-deployable design.*

2.2 Infrasound Microphones

To detect acoustic signals associated with volcanic activity, such as explosions, gas venting, or even lahars, low-cost infrasound sensors can be assembled using custom-built electret or MEMS microphones. These sensors are typically housed in PVC enclosures with simple wind noise filters, allowing for effective outdoor deployment in harsh environments. Each sensor can be built for less than $100 USD, not including the data logging system, making them an attractive option for budget-constrained observatories. They are easily integrated with low-power microcontrollers or with platforms like Raspberry Pi, to enable continuous recording and synchronization with other monitoring instruments. Despite their simplicity, these infrasound setups have proven effective in detecting and characterizing explosive volcanic activity in real time [Grangeon et. al.].

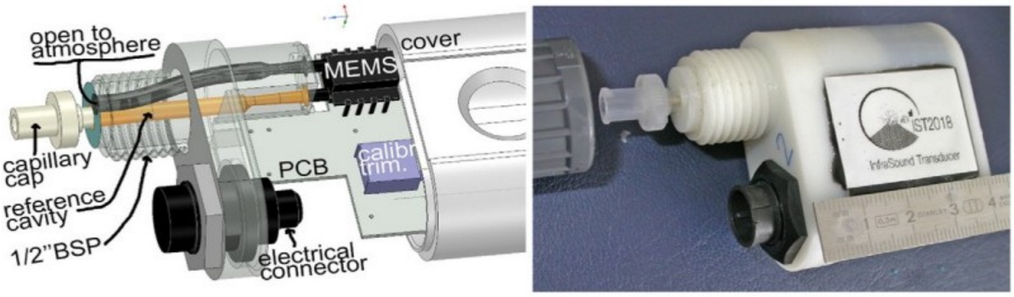

Fig. 3. *Left: Schematic block diagram of the infrasound sensor, illustrating the key components including the MEMS microphone, capillary tube, reference cavity, electronic board, and connector. These elements are assembled within the protective housing shown in the right panel [*Grangeon *et. al.].*

2.3 Thermal Cameras

Affordable thermal imaging for volcanic monitoring is possible with compact sensors like the FLIR Lepton (radiometric) or MLX90640, costing $100-$300 USD. Despite their low resolution and limited range (2-20 m), they are ideal for localized monitoring of vents and fumaroles. For a balance between cost and performance, Optris thermal cameras (e.g., PI 160, PI 400, Fig.4) offer higher resolution and radiometric imaging at $1500-8000 USD, suitable for crater or dome surveillance [3]. These can be paired with Raspberry Pi 4 or mini-PC for automated data streaming, offering a cost-effective alternative to traditional FLIR systems in resource-limited regions like Oceania.

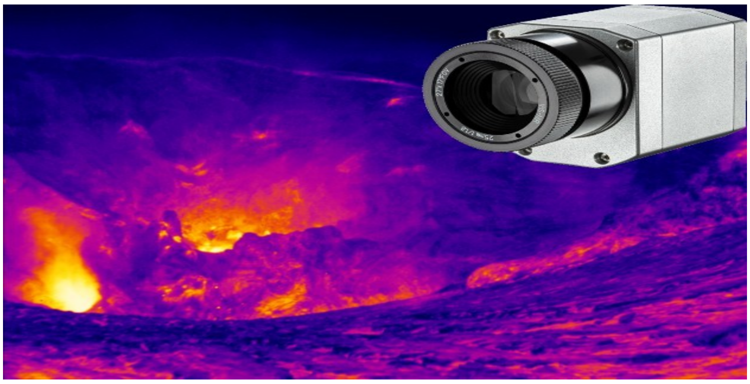

***Fig. 4**. Optris PI infrared camera — a compact device offering high optical and radiometric resolution, well-suited for reliable volcanic monitoring and research applications. Image obtained on Yasur volcano.*

2.4 Inexpensive Gas Monitoring

Monitoring volcanic gas emissions is essential for understanding magmatic processes and forecasting eruptions. However, commercial MultiGAS instruments—used to measure key gases such as sulfur dioxide (SO_2) and carbon dioxide (CO_2), often cost over $20,000 USD, limiting their accessibility in resource- constrained regions like much of Oceania. In response, low-cost MultiGAS prototypes have been developed using electrochemical sensors, bringing the total cost down to under $2,000 USD. Among these, systems like piGAS (Fig.5) [Pering et. al.], a Raspberry Pi- based gas analyzer, have demonstrated the potential for robust, field-deployable monitoring at a fraction of the cost. Similarly, piCam, a low cost, low-power SO_2 camera (Fig.6) [Wilkes et. al.], enables imaging of gas plumes for flux estimation and degassing analysis. While these devices typically offer lower accuracy and shorter sensor lifespans compared to commercial-grade instruments, they remain valuable for detecting gas trends, establishing baselines, and supporting early warning systems. They can be easily integrated with microcontrollers or single-board computers (e.g., Raspberry Pi, Arduino) for automated data logging and wireless transmission, providing a flexible and scalable solution tailored to the needs of remote volcanic regions in the Pacific.

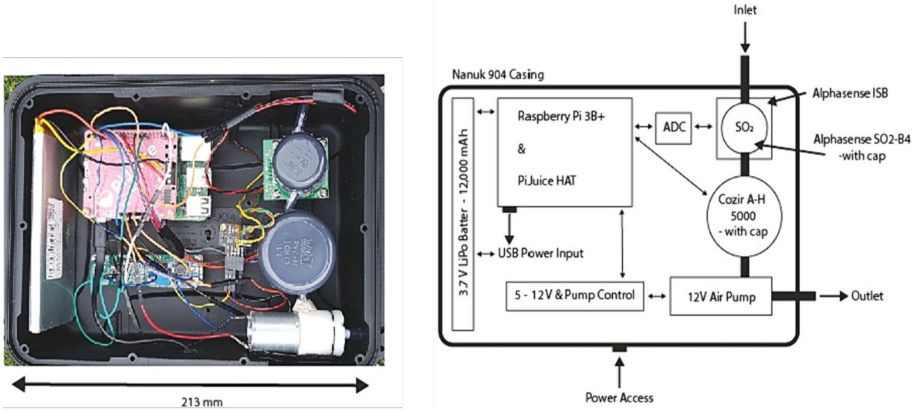

***Fig. 5.** PiGas, a low-cost approach to volcanic gas sampling [Pering et al., 2024].*

2.5 Remote Sensing & UAVs

Remote sensing technologies offer powerful and cost-effective tools for volcano monitoring, especially in isolated or difficult-to-access regions. Freely available satellite data from platforms such as Sentinel, MODIS, and TROPOMI enable regular monitoring of thermal anomalies, ash plumes, and sulfur dioxide (SO_2) emissions. Additionally, InSAR (Interferometric Synthetic Aperture Radar) data allows for the analysis of ground deformation without the need for ground-based instrumentation, making it ideal for remote island volcanoes. Complementing satellite observations, small unmanned aerial vehicles (UAVs) or drones (Fig.7) provide flexible, close-range monitoring capabilities. Equipped with thermal cameras, gas sensors, or optical imagers, these drones can be used for gas sampling, thermal imaging, and high-resolution mapping of craters and lava flows. Basic UAV systems suitable for volcanic applications can be assembled or purchased for approximately $1,000–$2,000 USD, making them a practical and scalable option for observatories and research teams operating in the Pacific Islands and other resource-limited regions.

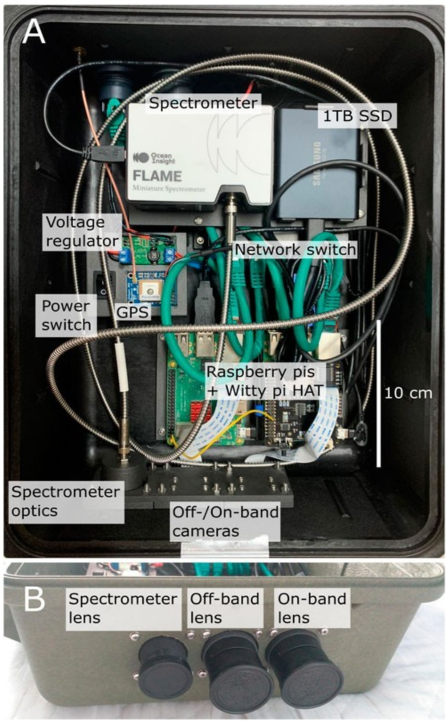

Fig. 6. *(A) Low cost SO_2 camera housed inside a Peli Case. Below, a view of instrument optical systems [*Wilkes *et. al.].*

2.6 Low-Bandwidth Data Transfer & Mesh Networks

In many parts of Oceania, reliable internet or cellular coverage is limited or absent, making traditional data transmission methods impractical for remote volcano monitoring. To address this, low-bandwidth communication technologies such as LoRa (Long Range Radio) and Wi-Fi relays can be employed to transmit data over rugged terrain and long distances with minimal power consumption. These systems can support local data storage and allow for intermittent uploads when connectivity becomes available—whether through mobile networks, satellite links, or manual data retrieval. To manage and visualize incoming data, open-source platforms like Grafana, ThingSpeak, or InfluxDB can be used to generate real-time dashboards and automated alerts. This approach enables reliable, low-cost data transmission and monitoring even in highly remote or infrastructure-poor regions, making it particularly well-suited to the geographical and logistical challenges of the Pacific Islands.

***Fig.** 7. Drones provide a practical solution for surveying hazardous or inaccessible volcanic terrain.*

2.7 Community-Based Monitoring

In remote and resource-limited regions, engaging local communities in volcano monitoring offers a sustainable and effective strategy to enhance early warning capabilities. Through targeted training programs, community members can be taught to observe and document visual cues, such as changes in gas emissions, thermal anomalies, or unusual sounds, and to report these anomalies to local authorities or observatories (Fig.8). SMS-based alert systems provide a simple yet powerful means of sharing real-time warnings, especially in areas with limited internet access. Additionally, the use of mobile applications allows residents to log observations, receive basic volcano updates, and access educational resources about volcanic hazards. This participatory approach not only strengthens the resilience of local populations but also extends the observational reach of formal monitoring networks, creating a valuable bridge between scientific institutions and the communities most at risk.

***Fig. 8.** Community-based monitoring is a powerful tool for tracking environmental changes and hazards.*

2.8 Capacity Building with Universities

Strengthening volcano monitoring in Oceania requires long-term investment in local expertise, and regional universities play a pivotal role in this effort. Institutions such as the University of New Caledonia (UNC), the University of the South Pacific (USP), and the University of Papua New Guinea (UPNG) serve as critical hubs for education, innovation, and applied research in Earth sciences. By integrating low-cost monitoring techniques—including seismic, gas, infrasound, thermal, and remote sensing technologies—into curricula and field-based training, these universities can equip students with practical skills tailored to the unique geophysical challenges of island environments. In addition to training, university departments can actively collaborate with national observatories and international partners to design and implement monitoring networks, co-lead station installation and maintenance, and participate in real-time data analysis and hazard interpretation. Engaging students and early-career scientists in these efforts not only builds a sustainable, locally rooted technical workforce, but also fosters a sense of regional ownership and scientific leadership. Moreover, academic institutions provide a platform for transdisciplinary collaboration, linking geoscience with disaster risk reduction, environmental policy, and community outreach. These partnerships are vital for ensuring that volcano monitoring is not only technically effective but also socially inclusive and resilient in the long term.

3. CONCLUSION

Doing More with Less. In the context of limited financial and logistical resources, Pacific Island nations can still achieve meaningful progress in volcanic hazard mitigation by embracing low-cost technologies and leveraging local knowledge and institutional capacity. The integration of affordable sensors, remote sensing tools, open-source platforms, and community-based approaches enables the sustained, real-time monitoring of active volcanoes, even in remote and infrastructure- poor settings. Coupled with targeted training programs and partnerships with regional universities, these innovations can strengthen early warning systems, enhance scientific research, and build local resilience. Importantly, these solutions are scalable, adaptable, and inclusive, making them well- suited to the diverse challenges faced across Oceania. By doing more with less, the region can chart a path toward sustainable volcanic risk reduction, rooted in regional ownership, innovation, and long-term capacity building.

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